Transport and Kinetic Processes in GaN Epitaxial Lateral Overgrowth

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Motivation—GaN is a wide band gap semiconductor with a broad range of potential applications, e.g., high-temperature electronics, optelectronics, chemical or biological sensors. GaN thin films usually have a high defect density, leading to poor performance. Epitaxial Lateral Overgrowth (ELO) has been shown to greatly reduce defect densities, often by factors of 100 or more. We are conducting fundamental studies of GaN growth kinetics during ELO.

Accomplishment—In ELO, a mask pattern of dielectric material is deposited on top of a GaN buffer layer. Further growth of GaN occurs selectively on exposed areas of the underlying buffer layer, and not on the dielectric material. Many coupled phenomena potentially contribute to observed ELO behavior, including mass transport and anisotropic growth kinetics. Scanning electron microscopy (SEM) is used to measure grown feature sizes. Growth rates depend strongly on the ELO pattern, i.e., size of the window opening, w, and mask width, m (or pattern "Pitch" p=w+m and fill-factor θ=w/p).

We examined the ELO growth efficiency, i.e., how much of the Ga reactant is incorporated into the growing ELO feature compared with the incorporation for unmasked, blanket growth. If the rate constant is high enough, the system is transport limited, and ELO growth efficiency is very high. As the reaction rate slows, for example through a decrease in temperature, the deposition rate now depends both on transport processes and on chemical kinetics. As a result, the ELO growth efficiency can be observed to drop. Finite-element analysis of ELO growth efficiency shows these effects quantitatively. In addition to these numerical studies, we have recently derived an analytical model that predicts the ELO efficiency, which depends importantly on the parameter Da=kδ/D, a surface Damkohler number, where k is the rate constant for the deposition reaction, δ is the reactor boundary layer thickness, and D is the diffusion constant.

$$\varepsilon = \frac{\theta\left(1+\mathrm{Da}\right)}{1+\theta\,\mathrm{Da}}$$

When Da>>1, chemistry rates are fast relative to mass transport, and the system is mass-transport limited. At the other extreme, when Da is unity or below, the system is limited by the chemistry rate. Figure 1 shows remarkable agreement between the above analytical model for ELO efficiency and the exact 2-D diffusion calculations.

Plotted in Fig. 2 are measured cross-sectional areas of the GaN ELO features versus the pattern Pitch. The observation that the 8:4 cross-sectional area matches the 100% efficiency line indicates that the inherent growth chemistry of the (0001) basal plane is very fast. Thus, this feature is in the transport-limited regime. The 1:16 feature is bounded by $(1\bar{1}01)$ facets. The observation that this point lies significantly below the unit-efficiency line is a reflection of the slow growth chemistry on that face.

Significance—These results have important implications for GaN ELO. Understanding the interplay between transport and kinetics allows us to extract the fundamental growth rates for individual crystal facets. For example, we have determined that the (0001) basal plane intrinsic growth kinetics is a factor of ten greater than for the $(1\bar{1}01)$ face, illustrated in Fig. 2. Knowledge of the fundamental growth kinetics enables us to adjust experimental growth conditions to optimize and manipulate growth morphology in ELO as well as in Cantilever Epitaxy (CE).

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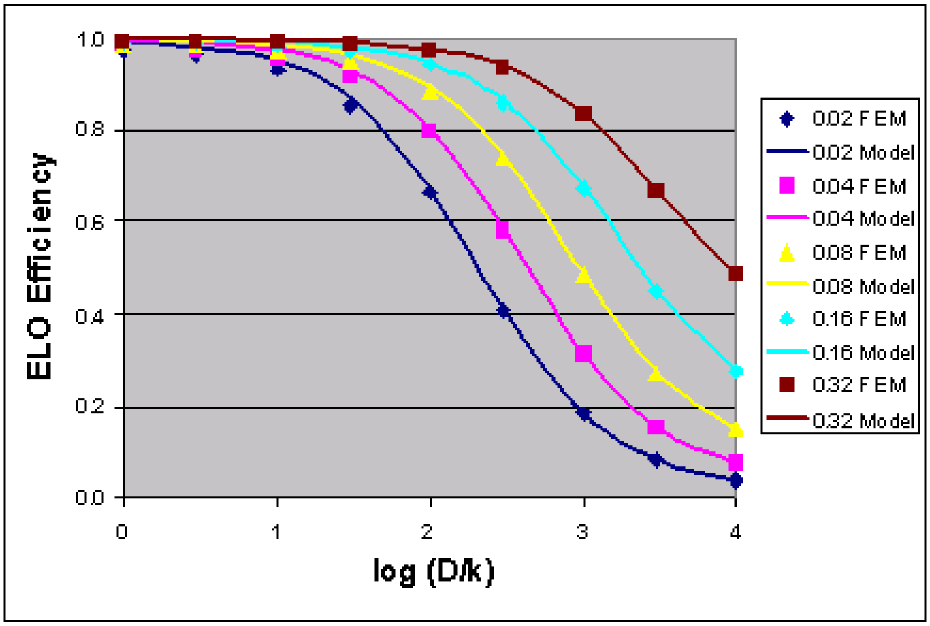

Figure 1. Theoretical ELO efficiency as a function of D/k, a measure of the relative rates of transport vs kinetics, for fill factors ranging from 0.02 to 0.32. Results of the exact finite-element calculation (FEM) are compared to the analytical model.

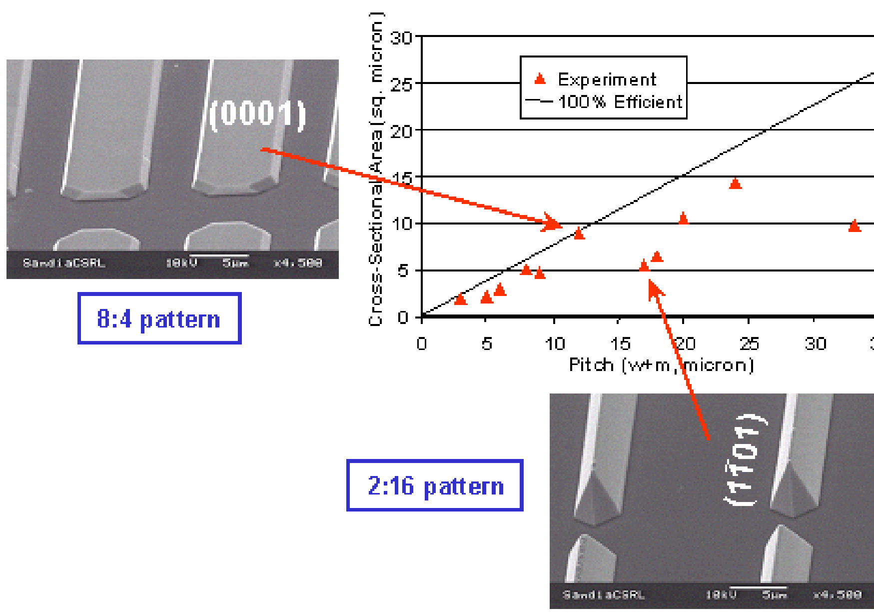

Figure 2 Measured cross-sectional areas of GaN ELO features grown on a variety of line patterns, varying w and m. Solid line denotes the expected result when ELO transport has unit efficiency.